AN AUTOCOLLIMATING MOUNTING FOR A CONCAVE GRATING.

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"For most spectroscopic problems Rowland's concave grating is an almost ideal aid," says W. Voigt in a recent article.[1] Its focal property enables us to dispense with lenses or mirrors, and so avoid the accompanying aberration, absorption and scattering of the light, and when once it is adjusted it is in focus for all orders of spectra. The usual form of mounting, however, is perhaps not quite so ideal. A large, perfectly dark room is required, the apparatus is heavy and cumbersome, or else lacking in rigidity, and what is still more important in some kinds of work, the position and direction of the emergent light change with each change of wave-length. Moreover it is not readily adapted to astronomical purposes.

The theory of the Rowland mounting is well known. If the source is placed at any point of the circumference of a circle constructed on the radius of the grating as a diameter, in the plane perpendicular to the ruling, the spectra will all be brought to a focus at points on the same circle. Of these spectra Rowland selected that which was at the center of curvature of the grating as giving a normal spectrum of constant scale. The necessary conditions were insured by placing the slit at the angle of a rectangular track, along the two arms of which moved the grating and the camera or eyepiece, the two rigidly connected by a rod of the proper length (Fig. 1). It is easily seen that while the source is fixed, the image is displaced in passing through the spectrum.

To avoid this objection, Lewis[2] interchanged the slit and camera, and Abney[3] fixed the position of the grating and camera and mounted the slit on an arm pivoted at the center of the line joining them (Fig. 2). These methods however require the source of light to be movable, which is usually undesirable and in some cases impracticable. Wadsworth[4] suggested several arrangements to overcome the difficulty, using auxiliary mirrors and more or less complicated mechanism, but these involve additional adjustments and loss of light. It may be added that the grating has also been used with parallel light in astronomical work, but the aberration is much greater than with Rowland's mounting.[5]

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[1] W. Voigt, *Phys. Zeits.*, 13, 217 (1912).

[2] E. P. Lewis, *Astrophys. Jour.*, 2, 1 (1895).

[3] W. deW. Abney, *Phil. Trans.*, 177, II., 457 (1886).

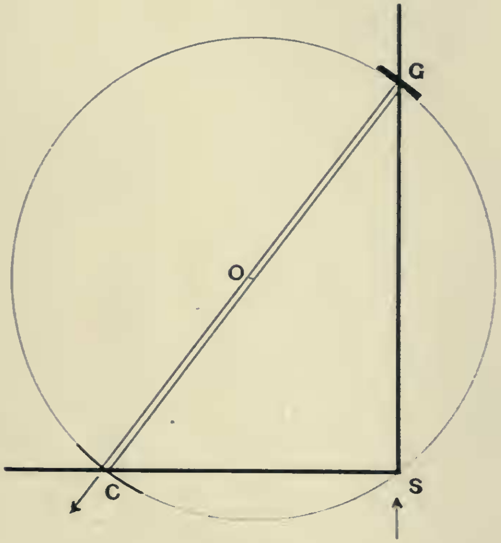

FIG. 1.

The method here discussed is briefly that of autocollimation. That part of the light is used which after being diffracted is returned toward the slit. If therefore the slit is on Rowland's circle, the spectrum will be formed on the same circle and one point of it will coincide with the slit (Fig. 3). The ingoing and outcoming beams may be separated when necessary by the usual reflecting prism, or by slightly tilting the grating. Thus a double slit may be

[4] F. L. O. Wadsworth, *Astrophys. Jour.*, 2, 370 (1895).

[5] F. L. O. Wadsworth, *Phil. Mag.* (6), 6, 119 (1903).

used, the light being sent through one slit and returned through the other. The wave-length of the light which is returned through the slit is given by the formula

$$\lambda = \frac{2e}{m} \sin \phi,$$

where e is the distance between consecutive rulings, ϕ the angle made by the light with the grating-normal, and m the order of the spectrum. It follows that at a given angle the order is twice that which is produced at the center of curvature.

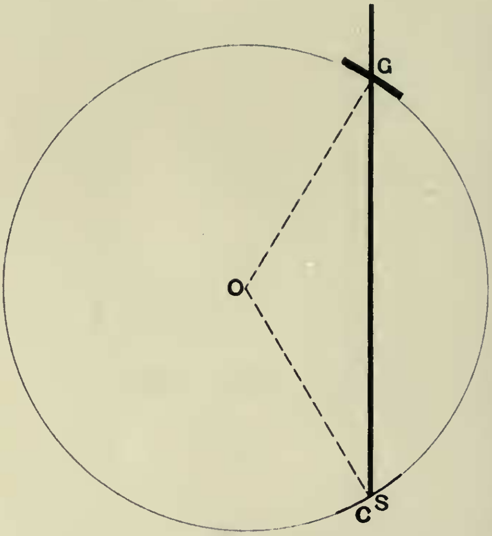

FIG. 2.

The principle of autocollimation has been often used with prism spectroscopes since it was first suggested by Duboscq[6] and Littrow.[7] It was first used with a plane grating by Liveing and Dewar,[8] and is employed in many recent grating spectroscopes. It has however, as far as I know, not been used with the concave grating, although one of the chief objections to this form of mounting—the reflection from the inner surface of the collimating objective—would be done away with. Perhaps the reason lies partly in the fact that the focal length changes in passing through the spectra, so that not only the inclination of the grating but also its distance from the slit must be altered, and in addition the focal plane is inclined to the direction of the light by an angle which varies with the setting. Thus in Fig. 3 the normals to the grating and to the spectrum make the same angle ϕ with the light, and the distance *GS* between grating and slit is $\rho \cos \phi$, where ρ is the radius of the grating. As the inclination of the grating is altered, that of the spectrum must be altered by an equal amount, and the distance *GS* properly changed.[9]

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[6] See H. Kayser, "Handbuch der Spectroscopie," I., 511.

[7] O. v. Littrow, *Wien. Ber.*, 47, II., 26 (1863).

[8] G. D. Liveing and J. Dewar, *Cambridge Proc.*, 4, 336 (1883).

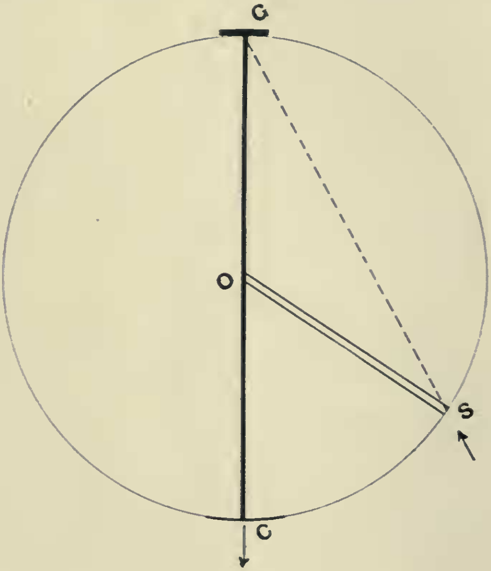

Fig. 3.

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[9] Since writing the above my attention has been called to an article by A. Eagle (*Astrophys. Jour.*, 31, 120, 1910) describing an autocollimating mounting for a concave grating. The mounting has the disadvantages mentioned, namely that the distance of the grating and inclination of the camera must be separately adjusted for each angle of incidence; disadvantages which it is sought to overcome in the mounting described in this paper. The advantages of the autocollimating mounting are discussed at length by Mr. Eagle with conclusions similar to those given here.

These adjustments however may be automatically made in the following manner. As in Rowland's mounting, let the slit be fixed at S (Fig. 3) and the grating be capable of sliding along the line GS and also of rotating about a vertical axis passing through its center. Now if two equal horizontal arms of length $\rho/2$ be pivoted at G and S respectively and hinged together at their other ends at O, and the arm OG be attached to the grating holder so as to be parallel to the grating-normal, the grating will keep the proper inclination as it slides along GS, for G and S are constrained to remain on the Rowland circle. This is in fact exactly equivalent to one half of a Rowland mounting. Moreover, if the camera is mounted to rotate about a vertical axis through S, and the arm OS is similarly attached normally to the photographic plate, the plate, if bent as usual into the arc of the proper circle, will continue to fit this circle throughout its motion and the spectrum will be in focus on all parts.

In practice the arms OG and OS would be excessively long and inconvenient, and would tend to bend the vertical axes at G and S. They could of course be balanced by a pair of similar arms on the other side, but the apparatus would then be still more cumbersome. The same effect may however be attained by a series of links of the "lazy-tongs" pattern, the total length when open being equal to the radius of the grating (Fig. 4). The first and last link on one side will correspond in direction to the arms OG and OS, and these are fixed normal to the grating and plate respectively. It is obvious that as either side may be used, all of the grating spectra become available.

A wooden model of the apparatus has been constructed for use with a six-foot grating, which exhibits the proposed arrangement and which in spite of its crudity renders excellent service. A more efficient mount is in process of construction. Sliding along a horizontal track is a block carrying a vertical pin on which as an axis turn the ends of the link motion and the platform for the grating. This latter may be clamped in any position to either of the adjacent link bars. At one end of the track is a fixed block with a similar vertical axis. This axis carries the other end of the linkage, a platform for the camera or eyepiece, and a support for the slit. These pieces may rotate independently[10] and the camera platform may be clamped to either bar.

The linkage is supported at its intersection by blocks which slide along the track. The arms of one of the parallelograms should be adjustable in length so that the framework may be exactly set to the grating, and so that gratings of slightly different radius may be used on the same stand. The grating slider is moved by a rod or screw running to the end of the track near the slit, the only function of the linkage being to produce the necessary rotation. There is therefore no great stress on the axes tending to bend them.

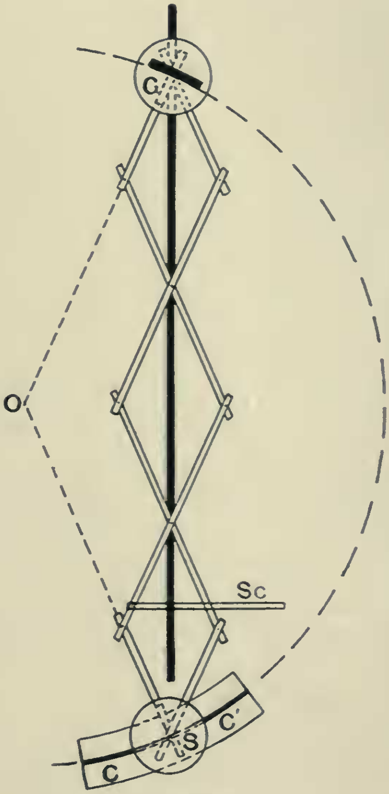

Fig. 4.

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[10] Rotation of the slit is convenient in making the adjustments.

The grating and slit are provided with the usual adjustments and also may be shifted on their platforms until their centers fall exactly in the axes of rotation. The camera is mounted on its platform on either side of the slit or preferably just above it, and may be adjusted so as to bring the plate into coincidence with the focal circle. If the latter position is used the grating must be raised until its center is in a horizontal plane midway between the slit and camera. For visual observations the plate holder may be replaced by an eyepiece which may be fixed if mounted above the slit, or if placed at one side is kept directed toward the grating by a simple device. The slit is provided with a reflecting prism and is made double so that light may be sent through one part and returned through the other. It is thus possible to obtain a monochromatic beam of high purity which will be sent always in the same direction. The apparatus is thus available for a threefold use: as a spectrograph, as an observing spectroscope, and as a monochromator; and it may be arranged so that no alteration need be made in passing from one to another of these forms.

The diagonal of any parallelogram of the linkage perpendicular to the track is proportional to sin ϕ, and therefore to the wave-length. A scale of equal parts placed across any part of the linkage perpendicular to the track, as at *Sc* (Fig. 4), will therefore give an approximate measure of the wave-length. Moreover by properly selecting the points on the bars across which the scale is placed, any scale may be adjusted to read wave-lengths directly. A more open scale may be placed on the track, but this will not be one of equal parts.

As everything is supported on one track, the apparatus may be made quite rigid, and at the same time, with the smaller gratings at least, portable. It will take up much less space than the other mountings. It is also more convenient as everything is in reach at the same time from the end of the track-source, slit, camera and handle for controlling the position of the grating. There is but one track to make true, and the other adjustments are no more difficult, and in some cases much easier, than in the Rowland mounting. A very desirable feature is that the slit, grating and camera may be connected by a light-proof bellows or other enclosure, so that the instrument may be used in an undarkened room. This bellows may be supported partly upon the blocks which carry the linkage.

The only part of the construction that may seem to offer difficulty is in making the linkage true, but this should not prove a serious obstacle. All that is necessary is that the four arms of each parallelogram shall be of equal length and that there shall be no play at the joints, and it should easily be possible to do this with sufficient accuracy. It may be added that the linkage, though extremely convenient, is not essential. The grating may be turned by hand to the angle corresponding to the wave-length desired, and then moved along the track until the light is focused on the slit. The camera may then be rotated until the spectrum is in focus.[11] In this way it may be possible to use gratings of much larger radius, and so avoid the errors produced in ruling on a surface of too great curvature.

The great compactness of the mounting makes it available for use in astronomical spectroscopy, from which the concave grating is practically barred when the Rowland mounting is used. The instrument may be mounted upon a telescope in the prolongation of its axis so that the slit lies in the focal plane of the objective. In the case of a star image the slit could be dispensed with, and the astigmatism of the grating would produce a spectrum of finite width. A more rigid and more convenient arrangement would be to mount the guides for the grating upon the tube of the telescope on the side opposite to the declination axis. The light could be brought to a focus by the objective at the side of the field nearest the slit and thrown upon the slit by totally reflecting prisms. No harm would be done by any possible astigmatism which would merely be added to that of the grating, and slight irregularities in driving would be equally harmless.

It remains to consider the character of the spectra produced. The chief advantages of Rowland's mounting are that the spectrum is normal and always of the same scale, and that the plate is perpendicular to the direction of the light. In the autocollimating mounting none of these conditions are fulfilled. These disadvantages are shared by all prism spectrographs. They are however less with the grating, and, a matter of great importance, the amount of the variations may be readily calculated and allowed for.

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[11] This is in fact the arrangement described by Eagle (l. c.).

The deviation of the spectrum from a normal one might seem to be a serious objection, but as a matter of fact the deviation is much less than might be thought. Thus on a plate of the usual size, the maximum deviation from a normal scale is about one Ångstrom, and when using a comparison spectrum the maximum difference between the corrections for two lines say ten Ångstroms apart would be about one twentieth of an Ångstrom. Moreover the deviation from the normal scale may be accurately allowed for, being of the form

$$\frac{\lambda\, s_1 s_2}{4\rho^2},$$

s_1 and s_2 being the distance of the line in question from the two lines selected to establish the scale, and λ_0 the wave-length which is returned through the slit. This correction is the same as that necessary when using a plane grating in the autocollimating position.

The varying amount of dispersion is an objection in some classes of work, especially where plates are taken in different regions of the spectrum. The scale varies as sec ϕ, and therefore is somewhat larger than that of the same order in the normal mounting, especially when the angle is large. Moreover, in a given direction the order of the spectrum is doubled and therefore the dispersion is more than twice as great. This is an important property of the autocollimating mounting, since twice as many orders are available for observation. Thus with a 15,000 grating, four complete spectra may be observed instead of only two.

The inclination of the photographic plate will sometimes be a more serious objection. Great care should be taken in its register. This objection as somewhat weakened by the increase of the dispersion with the inclination, so that an error due to imperfect register is proportional to sin ϕ instead of tan ϕ. The error is greatly reduced when using comparison spectra on the same plate.

Finally as to the definition. Kayser[12] gives for the greatest permissible length of a grating used in the customary position—*i. e.,* the length when the difference in phase between the extreme rays amounts to π—the expression

$$L = 2\rho \sqrt[4]{\frac{2e \cot \phi}{m}}$$

and the same formula holds for the autocollimating position. Comparing the same order of spectra we see that as ϕ is less in the second case (and therefore cot ϕ greater) the limiting length of grating would be greater; so that a given grating will be farther from this limiting value and hence will have better definition. The grating is in fact in the position of minimum deviation, and the aberration is equally divided between the incident and diffracted beams and is therefore a minimum.

To sum up: the mounting here described differs from the usual mounting for a concave grating by employing the principle of autocollimation. It possesses the advantages of the Rowland mounting of having all spectra automatically in focus, but differs from it in having greater compactness, convenience and rigidity. The adjustments are easier and the necessity of a dark room is avoided. The definition in the same order is somewhat greater, and twice as many orders may be observed. The deviations of the spectrum from the normal type are small and may be accurately allowed for. The instrument may be readily adapted to work in astronomical spectrography.

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[12] H. Kayser, "Handbuch der Spectroscopie," I., 458.